DOE/NV/25946--3415

Continued Data Acquisition Development

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NST13-MUON-PD2Na Task 3 Report

This work was done by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy and supported by the Site-Directed Research and Development Program.

Summary

Task 3 focused on improving techniques for integrating data acquisition of secondary particles correlated in time with detected cosmic-ray muons. Scintillation detectors with Pulse Shape Discrimination (PSD) capability show the most promise as a detector technology based on work in FY13. Typically PSD parameters are determined prior to an experiment and the results are based on these parameters. By saving data in list mode, including the fully digitized waveform, any experiment can effectively be replayed to adjust PSD and other parameters for the best data capture. List mode requires time synchronization of two independent data acquisitions (DAQ) systems: the muon tracker and the particle detector system. Techniques to synchronize these systems were studied. Two basic techniques were identified: real time mode and sequential mode. Real time mode is the preferred system but has proven to be a significant challenge since two FPGA systems with different clocking parameters must be synchronized. Sequential processing is expected to work with virtually any DAQ but requires more post processing to extract the data.

Background

Cosmic-ray muon tracking and imaging in tomographic mode has been shown to be effective for locating and imaging high-Z materials, even when shielded by lower Z materials, but cannot determine the isotopic content of these imaged high-Z items. Muon induced fission as well as other processes can yield a secondary particle (neutron or gamma) in coincidence with a tracked cosmic-ray muon incident on a material of interest. Correlating secondary particles with tomographic muon imaging shows promise for determination of the isotopic content of the high-Z materials. This requires correlating muons with secondary particles with time resolution 5 ns or less, which is the time resolution of drift tube muon tracking technology employed on the Configurable Muon Tracker (CMT). The requirement that this system can be ultimately fielded with minimal setup time led to the decision to pursue off-the-shelf digital data acquisition (DAQ) systems. The DAQ system requirements include: the capability to be time synchronized with the external clock of the muon tracker, to make real-time pulse shape discrimination (PSD) determination, and to be upgradable to allow readout of the full waveform of the scintillation detector.

Pulse shape discrimination is a technique that exploits the different physical interactions of neutrons and gammas with a scintillating material. Gammas (as well as electrons and muons) interact directly with the scintillating material via the electromagnetic force, while neutrons must scatter and indirectly deposit energy in the material. This leads to neutrons having a longer tail on the scintillation pulse. Historically PSD scintillators have been liquids, such as EJ-301 and EJ-309. Recently a new plastic PSD material was developed and is being marketed by Eljen Technology as EJ-299. Detectors constructed using EJ-301 and EJ-299 were coupled to the DAQ systems for testing. The DAQ system uses the CAEN model DT5751 digitizer with a PSD firmware option. The CAEN system uses a dual-time window integration technique for PSD, as shown in Figure 1, and has the ability to save the entire waveform to file. The challenge for list mode acquisition of the muon and secondary particle signature is that each DAQ system needs to run independently of the other system. Unlike standard nuclear counting techniques where one system can be considered the master and the other the slave, the CAEN and the CMT were both designed as masters. In order to capture all of the data in a full list mode system, all data are saved and the challenge is provide a common time stamp for processing the data. Unfortunately, integrating data from two independent clocks is a non-trivial problem, requiring a master clock and start signal to synchronize the two DAQ systems.

$$PSD = \frac{Q_{LONG} - Q_{SHORT}}{Q_{LONG}}$$

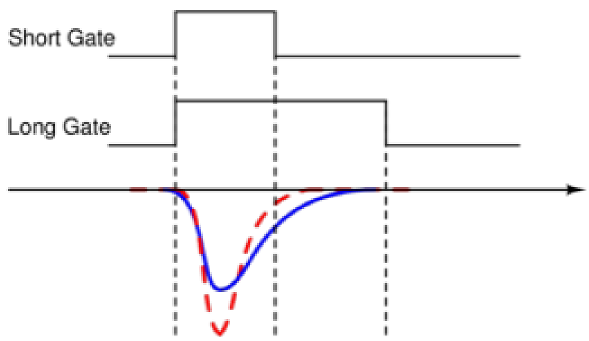

Figure 1. Diagram showing method for calculating PSD parameter using the CAEN DT5751 digitizer. A neutron will produce a pulse with a longer tail, shown in blue, giving a larger PSD parameter due to the additional charge measured in the long integration time, Q_{LONG}.

Synchronizing the CMT with the CAEN digitizer presented unique challenges due to the design of the DAQ on the CMT. The CMT uses 24 time to digital converter (TDC) boards with integrated field programmable gate arrays (FPGAs) mounted to read drift tube outputs directly. All of the TDC boards must have common timing since the timing and drift tube array geometry are the only fit parameters in determining a muon trajectory. By accurately determining both the time of each muon hit and the drift time, the drift radius can be calculated. Once the radius is known, tracks are fit using algorithms based on the basic tracking geometry illustrated in Figure 2. One of the TDC boards provides a clock out signal that is fanned out and used for common timing of the entire DAQ system. Synchronizing external detectors requires finding a method to synchronize with the CMT common timing. The two approaches that were explored are illustrated in the block diagram in Figure 3. The external detector can send a timing signal that is recorded by the CMT's DAQ, or a clock signal can be output from the CMT to synchronize with the external DAQ systems.

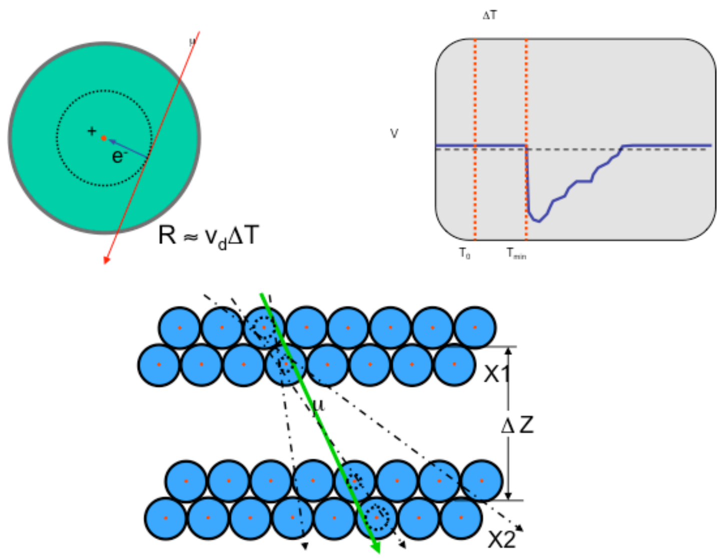

Figure 2. Diagram showing the geometry used in tracking muons using drift tubes. The timing of the muon pulse is the primary parameter, together with the known geometry, used in the fit.

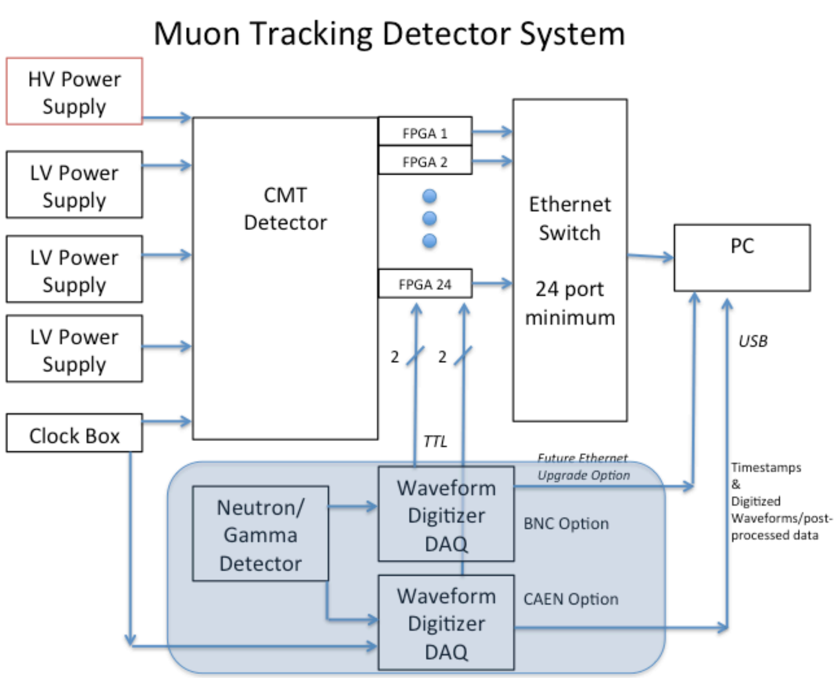

Figure 3. Block diagram of DAQ system used in the CMT. The blue box shows two approaches to synchronizing signals from external detectors to the system.

The CAEN digitizer employs an onboard FPGA which has the capability to easily upload firmware customized for various features, including PSD capability. The PSD firmware is available from the vendor and CAEN provides an API that allows the user more control and processing in the unit. The waveform is continuously digitized and the PSD calculation is made when the device is triggered internally or externally. This digitizer can save the entire waveform in addition to making real-time PSD calculations. The internal trigger option will be used when coupling this system to the CMT to save all data in list mode. By saving the entire waveform, one can post process the list mode data and modify the variables such as timing window lengths and fit parameters to effectively replay experiments to extract more information and optimize techniques. Once the PSD calculation is determined, the PSD parameter is saved to the computer along with its timestamp. The full waveform can also be saved to disk with a timestamp.

Synchronizing the CAEN with the CMT required new daughter boards to be designed, built, and installed on the CMT. These boards retained the functionality of the earlier boards by maintaining the ability to input up to two logic signals per board for timing measurements. The improvement on the new daughter boards was a clock out signal and a reset signal to connect the external DAQ system with the CMT clocking system. Synchronization of the internal clock of the CAEN system with the CMT clock is required to save time stamped data. Figure 4 shows a logic diagram of the clock synchronization. Algorithms were developed to save waveform and PSD data along with the timestamp from the CAEN to the control computer. Multiple changes have been made to the daughter boards and the firmware controlling the daughter boards as part of the development process, and the latest version along with software is being tested.

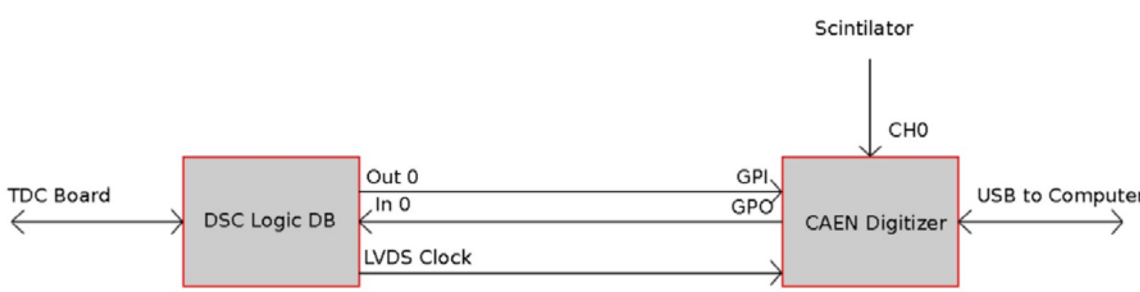

Figure 4. Logic diagram of interfacing the CAEN Digitizer with the CMT daughter boards in real time mode.

Real Time method

The real time method requires synchronization of two FPGA clocks that are designed to run independently. The CMT has 24 FPGA boards with a total of 576 channels for muon counting. The timestamp of each event is critical to tracking the muons. This requires that the CMT clock be used as the master clock for any additional DAQ. With this requirement, the CAEN digitizer's clock must be synchronized with the muon master clock.

The CAEN DT5751 is a programmable DAQ that has many features that can be turned on and off or controlled by software. CAEN provides an extensive API for programming the unit. The CMT's clock rolls over every 90 minutes (40-bit counter at 5 ns), but the CAEN rolls over every 17 seconds (30-bit unsigned counter at 62.5 MHz). This problem required us to modify the CMT's hardware to become the master and resync the CAEN and itself at a rate faster than 17 seconds and include a rollover register to store longer timestamps for longer acquisitions. These changes required a new PCB to be designed and built to replace the older daughter boards along with firmware updates.

Sequential Method

Sequential method allows the CAEN to run without a synchronized clock and relies on the output trigger of the CAEN to time the pulses. The CAEN has 4 input channels but only one output trigger which potentially will result in recording null data sets. The output trigger of the CAEN fires when any channel detects a signal over threshold. The output trigger signal is sent to the CMT and data from all 4 channels is saved to file. The CMT receives the trigger signal in the daughter board input channel. These are dedicated input channels which record each trigger along with a time stamp derived from the CMT's clock**.**

Synchronization of the CAEN signals requires significant post processing of the data because no timing information relative to the muon events is saved with the CAEN data. All timing information is contained in the daughter board event file saved with time stamps from the CMT clock. Times are assigned to each CAEN event by traversing the data files sequentially. The timestamp is grabbed from the first daughter board event and this time is assigned to the first entry in each CAEN data file. In general there will be eight independent entries from the CAEN, one entry for the PSD parameter from each channel and one entry for each digitized waveform. The algorithm moves to the next entry in the daughterboard file and sequential entries in the CAEN data files to assign times. Once times are assigned, algorithms to correlate the data can be used. Any disruption of the sequential nature of the files will render all subsequent data invalid. This technique is being developed as a backup to the real-time method and is expected to work on virtually any DAQ.

Conclusions

Synchronization of the CAEN DAQ system to the muon DAQ has proven to be a significant challenge. The real time method relies on common timing between the two FPGA clocks and has required many revisions of software, hardware, and firmware. Development on the sequential method has been initiated as a backup if real time does not prove to be successful in testing. The advantage to the real time method is saving all data, but the time synchronization is a serious challenge. Synchronization has been developed using one of the 24 TDC boards from the CMT and will need to be tested on the full system. Once tested in early FY15, the best method can be identified and the final correlation algorithms can be implemented for analysis of list mode secondary particle data.